Localization Techniques for Underwater Acoustic Sensor Networks

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Outline

• Ocean Monitoring Systems

• Underwater Acoustic Sensor Networks (UASN)

• Localization Techniques for UASNs

• Open Issues and Future Directions
Ocean Monitoring Systems- ARGO Project

- Argo floats measure the temperature and salinity of the upper 2000 m of the oceans
- Over 3000 profiling floats
Ocean Monitoring System - Seaweb

US Navy Project (since 1980s)
- Seaweb includes AUVs, gliders, buoys, repeaters and ships
- Devices communicate via telesonar, radio and satellite links
Traditional Ocean Monitoring Systems and UASNs

Traditional equipments

- Disconnected, individual and large
- Transmit data only when they are close to surface or by underwater cables
- No node-to-node communications

UASNs:

- Relatively small and less expensive underwater sensor nodes
- Sensor nodes communicate underwater via acoustics
Underwater Acoustic Communications - I

• Why acoustics?
  • Radio signals attenuate rapidly
  • Optical signals scatter

• Acoustic signals attenuate less and they are able to travel further distances
  • Bandwidth of the acoustic channel is low
    • For 10-100km (long-range), the bandwidth is a few kHz
    • For 1-10km (medium range), the bandwidth is in the order of 10kHz
    • For <100m (short range), the bandwidth is only over a few hundred kHz
Underwater Acoustic Communications - II

• Acoustic Channel Cont’d
  • Data rates are low
    • The maximum attainable range-rate product is 40 km.kbps
    • Data rate can be increased by using short range communications

<table>
<thead>
<tr>
<th>Span</th>
<th>Range (km)</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short range</td>
<td>&lt;1</td>
<td>~20 kbps</td>
</tr>
<tr>
<td>Medium range</td>
<td>1–10</td>
<td>~10 kbps</td>
</tr>
<tr>
<td>Long range</td>
<td>10–100</td>
<td>~1 kbps</td>
</tr>
<tr>
<td>Basin scale</td>
<td>3000</td>
<td>~10 bps</td>
</tr>
</tbody>
</table>

• The acoustic channel has low link quality due to the multi-path propagation and the time-variability of the medium

• Long propagation delay
  • $1.5 \times 10^3$ m/s vs. $3 \times 10^8$ m/s
Challenges of Localization in UASNs

- Underwater Communications
- Mobility
- Limited battery life
- GPS cannot be used underwater
  - High-frequency GPS signal does not propagate well
- GPS-free WSN techniques cannot be directly applied to UASNs
  - Extensive messaging
  - Infrastructure
Localization Basics

Localization has two steps

• Collecting information about the neighbor nodes
  – Range, angle, connectivity

Ranging Techniques:

• Received Signal Strength Indicator (RSSI)
• Angle-of-Arrival (AoA)
• Time Difference of Arrival (TDoA)
• Time of Arrival (ToA)

• Using this information in lateration
Outline

• Ocean Monitoring Systems

• Underwater Acoustic Sensor Networks (UASN)

• Localization Techniques for UASNs

• Open Issues and Future Directions
Localization Techniques for UASNs

- Distributed Protocols
  - Estimation-based Protocols: DNRL, MSL, AAL, LDB, LSL, UPS, LSL, USP
  - Prediction-based Protocols: SLMP
- Centralized Protocols
  - Estimation-based Protocols: MASL, ALS
  - Prediction-based Protocols: CL


Distributed and Estimation-based Localization Techniques

- **DNRL (Dive and Rise Localization)**
  - DNR beacons learn coordinates via GPS
  - Descend and ascend periodically
  - Broadcast localization messages at several intervals
  - Sensor nodes do lateration after receiving localization messages from at least three DNR beacons

- **MSL (Multi-Stage Localization)**
  - Localized nodes become reference nodes for the non-localized nodes
  - Sensor nodes do lateration after receiving localization messages from DNR beacons or localized nodes
  - DNRL and MSL uses ToA for ranging
    - Require synchronization
  - Coverage of MSL is larger whereas the error of DNRL is lower
Localization Techniques for Underwater Acoustic Sensor Networks

Distributed and Estimation-based Localization Techniques

- **AAL (AUV-Aided Localization)**
  - AUV broadcasts “wake-up messages” from different places on its route
  - An underwater sensor node sends a request packet and AUV replies with a response packet
  - This request/reply packet pair enables two-way ranging
  - The underwater node does lateration

- **LDB (Localization with Directional Beacons)**
  - AUV roams above the area of operation and uses a directional acoustic transceiver to broadcast its coordinates
  - Sensor node maps AUV coordinates on its plane and calculates coordinates
Localization Techniques for Underwater Acoustic Sensor Networks

Distributed and Estimation-based Localization Techniques

- **LSL (Large-Scale Hierarchical Localization)**
  - Anchor nodes broadcast localization messages
  - Underwater nodes exchange beacons periodically to measure the distances to their neighbors
  - If an ordinary node gathers adequate localization messages it does lateration
  - A localized node may become a reference node

- **USP (Underwater Sensor Positioning)**
  - Anchor coordinates are mapped onto the 2D plane that the sensor resides on
  - Bilateralation and trilateralation are used to estimate sensor coordinates
Distributed and Prediction-based Localization Technique

- **SLMP (Scalable Localization with Mobility Prediction)**
- Anchor nodes and ordinary nodes predict their locations by using their previous coordinates and their mobility patterns.
- Anchor nodes periodically check the validity of their mobility pattern:
  - An anchor node, after predicting its location, uses surface buoy coordinates and distance measurements to buoys to estimate its location.
  - If the Euclidean difference between the predicted and estimated locations is less than a threshold, the anchor node assumes its mobility model is accurate.
  - Otherwise, the anchor node runs its mobility prediction algorithm, determines the new mobility pattern.
- New model parameters are broadcasted to the ordinary nodes.
Localization Techniques for UASNs

Distributed Protocols
- Estimation-based Protocols
  - DNRL, MSL, AAL, LDB, LSL, UPS, LLS, USP
- Prediction-based Protocols
  - SLMP

Centralized Protocols
- Estimation-based Protocols
  - MASL, ALS
- Prediction-based Protocols
  - CL

References:


Centralized and Estimation-based Localization Techniques

- **MASL (Motion-Aware Self Localization)**
  - Underwater nodes collect distance estimates to their neighbours
  - Distance estimates are fed into an iterative estimation algorithm at the end of the mission
  - At each iteration, the algorithm refines position distributions by dividing the area of operation into smaller grids and selecting the area in which the node resides with the highest probability

- **ALS (Area-Based Localization Scheme)**
  - Anchors partition the region into non-overlapping areas by sending messages at varying power levels
  - An underwater sensor listens to anchor messages, keeps a list of anchors and their power levels, and sends this information to a sink node
  - The sink knows the coordinates of the anchors and determines the location of the sensor node
Centralized and Prediction-based Localization Technique

• Collaborative Localization (CL)
  – A follower node predicts its location by using its previous location and the displacement of the profiler
  – The displacement of the profiler is attained by periodically measuring distances in between via ToA
## Localization Protocols

<table>
<thead>
<tr>
<th></th>
<th>Distributed/Centralized</th>
<th>Estimation/Prediction</th>
<th>Anchor Type</th>
<th>Ranging Method</th>
<th>Communication</th>
<th>Synchronization</th>
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</thead>
<tbody>
<tr>
<td>DNRL [3]</td>
<td>Distributed</td>
<td>Estimation</td>
<td>Non-propelled mobile anchors</td>
<td>ToA (one-way ranging)</td>
<td>Silent</td>
<td>Yes</td>
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<tr>
<td>MSL [4]</td>
<td>Distributed</td>
<td>Estimation</td>
<td>Non-propelled mobile anchors and reference nodes</td>
<td>ToA (one-way ranging)</td>
<td>Iterative</td>
<td>Yes</td>
</tr>
<tr>
<td>AAL [5]</td>
<td>Distributed</td>
<td>Estimation</td>
<td>Propelled mobile anchor (AUV)</td>
<td>ToA (two-way ranging)</td>
<td>Silent</td>
<td>No</td>
</tr>
<tr>
<td>LDB [6]</td>
<td>Distributed</td>
<td>Estimation</td>
<td>Propelled mobile anchor (AUV)</td>
<td>Range-free</td>
<td>Silent</td>
<td>No</td>
</tr>
<tr>
<td>LSL [7]</td>
<td>Distributed</td>
<td>Estimation</td>
<td>Surface buoys, underwater anchors, and reference nodes</td>
<td>ToA (one-way ranging)</td>
<td>Iterative</td>
<td>Yes</td>
</tr>
<tr>
<td>UPS [9]</td>
<td>Distributed</td>
<td>Estimation</td>
<td>Stationary anchors</td>
<td>TDoA</td>
<td>Silent</td>
<td>No</td>
</tr>
<tr>
<td>LSLS [10]</td>
<td>Distributed</td>
<td>Estimation</td>
<td>Stationary anchors and reference nodes</td>
<td>TDoA</td>
<td>Iterative</td>
<td>No</td>
</tr>
<tr>
<td>SLMP [12]</td>
<td>Distributed</td>
<td>Prediction</td>
<td>Surface buoys, underwater anchors, and reference nodes</td>
<td>ToA (one-way ranging)</td>
<td>Iterative</td>
<td>Yes</td>
</tr>
<tr>
<td>MASL [13]</td>
<td>Centralized</td>
<td>Estimation</td>
<td>No anchors</td>
<td>ToA (one-way ranging)</td>
<td>Active</td>
<td>Yes</td>
</tr>
<tr>
<td>ALS [14]</td>
<td>Centralized</td>
<td>Estimation</td>
<td>Anchors with variable power levels</td>
<td>Range-free</td>
<td>Active</td>
<td>No</td>
</tr>
<tr>
<td>CL [15]</td>
<td>Centralized</td>
<td>Prediction</td>
<td>No anchors</td>
<td>ToA (one-way ranging)</td>
<td>Active</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Distributed VS Centralized Localization

• Distributed techniques:
  • Suitable for a large number of applications
    • online monitoring, target tracking, coordinated motion
  • Computational burden is on the sensors

• Centralized techniques:
  • Computational burden is shifted from the sensors
  • Work offline (MASL) and coarse-grained (ALS)
  • Unsuitable for data tagging, online monitoring and tracking applications
Estimation VS Prediction Based Localization

- Estimation can be used for stationary and mobile UASNs

- Prediction-based schemes inherently address localization of mobile UASNs

- Their performance is closely coupled with the mobility of the sensors
Open Issues

• Analyzing the performance of prediction-based localization schemes on accurate mobility models

• The impact of various localization techniques on the performance of networking in UASNs and other U ASN applications
  – Geographic routing algorithms and geographic clustering schemes

• Cross layer design
  – Using link quality information in selecting anchor nodes or reference nodes
Publications on UASNs

Journals


Conferences


Thank you

Questions?

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